Behaviour of Soft Soil Improved with Vertical Drain Accelerated Preloading Incorporating Visco-Plastic Deformation

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CERTIFICATION

I, Babak Azari, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Civil and Environmental Engineering, University of Technology, Sydney, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualification at any other academic institution.

Babak Azari

May 2015

I would like to dedicate my thesis to my beloved parents

ABSTRACT

Creep also known as time dependant viscous behaviour of soil is a significant part of the soft soil settlement, which may cause substantial deformation in the long-term. Post-construction settlement of soft soils can be significant throughout the life time of the structure. Consequently, to minimise the post-construction deformation and improve the bearing capacity and the shear strength of the soft soil deposits, preloading combined with vertical drains is frequently used as a ground improvement technique.

Soil disturbance induced by the installation of vertical drains results in reducing the horizontal soil permeability and the shear strength in the disturbed zone. Thus, the soil disturbance contributes to the reduced hydraulic conductivity and overconsolidation ratio (OCR) of the soil in the vicinity of drains, influencing soil deformation. Based on the available literature, there is a lack of understanding with respect to the combined effects of the overconsolidation ratio and the hydraulic conductivity profiles in disturbed zone and the nonlinear visco-plastic behaviour of soft soils. These combined effects influence the creep parameters and the settlement rate and accordingly deformation of soft soils improved using vertical drains assisted preloading.

In this research, the elastic visco-plastic model has been incorporated in the consolidation equation to investigate the effects of soil disturbance induced by the installation of vertical drains on the long term performance of soft soil deposits. The elastic visco-plastic model consists of a nonlinear creep function with a creep strain limit. The applied elastic visco-plastic model is based on the framework of the modified Cam-Clay model, capturing the soil creep during the excess pore water pressure dissipation. Finite difference formulations for fully coupled one dimensional axisymmetric consolidation have been adopted to model the time dependent behaviour of the soft soil, combining both vertical and radial drainage. Crank-Nicholson scheme is applied in formulating the finite difference procedure, since this scheme uses two steps in partial differentials of pore water pressure over distance, stabilising the process quicker.

An array of laboratory tests were carried out using Oedometer and small and large Rowe cells apparatus to verify the developed numerical code for the axisymmetric solution. The Oedometer tests were conducted to choose the soil mixtures for disturbed and intact zones. Two sets of small Rowe cell tests were carried out on selected soil mixes to obtain the elastic visco-plastic model parameters. A large Rowe cell was used to carry out the vertical drain assisted consolidation tests by installing a vertical drain in the centre of the cell. To simulate the disturbed zone for the area surrounding the vertical drain, a different mix with reduced permeability was used. A compacted sand column covered with flexible porous geotextile was installed in the centre to simulate the vertical drain. The cell is fully instrumented and consists of a vertical displacement gauge at the surface level and nine pore water pressure transducers on the sides and at the base of the cell. Comparison of laboratory measurements and numerical predictions shows that the proposed finite difference procedure incorporating the elastic visco-plastic soil behaviour is appropriate for the consolidation analysis of preloading with vertical drains.

Two case studies of vertical drains assisted preloading were numerically simulated to investigate the effects of soil disturbance caused by the installation of vertical drains. Different variations of the overconsolidation ratio and hydraulic conductivity in the disturbed zone in combination with time dependant behaviour of soft soils were considered. Different OCR and initial hydraulic conductivity profiles in the disturbed and transition zones result in various visco-plastic strain rates and creep strain limits. Consequently, the induced changes in visco-plastic strain rate and creep strain limit influence the settlement rate at any given time. Therefore, the selection of OCR and initial hydraulic conductivity profile in the disturbed zone has a significant effect on selecting unloading time and therefore the post construction settlement. It was observed that the creep coefficient and the creep strain limit vary during loading and unloading and also during excess pore water pressure dissipation. The creep coefficient and the creep strain limit are functions of the vertical effective stress and time. The proposed solution can readily be used by practicing engineers considering layered soil deposits, time dependent loading and unloading, while incorporating combined effects of soil disturbance and visco-plastic behaviour.

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PUBLICATIONS

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A	experimental constant
a	the compressibility of the linear spring
a_v	constant over load increment for small void ratio changes
B	experimental constant
b	the compressibility of the spring
C	experimental constant
C_α	secondary compression index
C'_α	post-surcharge secondary compression index
C''_α	post-surcharge secant secondary compression index
$C_{\alpha e}$	the rate of secondary compression
C_c	conventional compression index
C_r	conventional recompression index (unloading and reloading data)
c_k	permeability change index
c_v	coefficient of consolidation
D	experimental constant
e_0	initial void ratio
e_1	the initial value of void ratio
e_{ref}	void ratio at effective stress equal to σ'_z on reference time line
e_z	void ratio for a particular applied effective stress σ'_z
e_{EOP}	void ratio when the excess pore water pressure has fully dissipated
g	visco-plastic settlement rate
H	layer depth
h	hydraulic head (static pressure head)
i	horizontal node coordinator
j	vertical node coordinator
k_0	initial permeability
k_1	vacuum pressure reduction factor by depth
k_2	vacuum pressure reduction factor by radius
k_{ave}^A	average disturbed zone permeability for Case A
k_{ave}^B	average disturbed zone permeability for Case B
k_{ave}^C	average disturbed zone permeability for Case C
k_{ave}^D	average disturbed zone permeability for Case D
k_{ave}^E	average disturbed zone permeability for Case E
k_{ave}^F	average disturbed zone permeability for Case F
$k'_r(r)$	coefficients of permeability for horizontal direction for disturbed zone
$k'_z(r)$	coefficients of permeability for vertical direction for disturbed zone

k_d	the effect of both work hardening and strain rate hardening
k_r	coefficients of permeability for horizontal direction for intact zone
k_{si}	the horizontal coefficient of permeability of remoulded soil
k_z	coefficients of permeability for vertical direction for intact zone
l	total depth
m_v	coefficient of volume compressibility
n	model parameter
OCR	overconsolidation ratio
p_0	the applied vacuum pressure
Q	The flow in the slice at a distance r
q_0	the constant loading
R	disturbed zone radius
R'_s	effective surcharge ratio
r	radial coordinate
r_d	disturbed zone radius
$\mathrm{r_e}$	the equivalent influence radius
r_p	partial disturbed zone radius
r_s	smear zone radius
r_w	vertical drain zone radius
$\mathrm{S_p}$	drain spacing
S_t	average total settlement
S_u	shear strength for disturbed and transition zones
$(S_u)_{NC}$	normally consolidated shear strength of soil
T_h	horizontal time factor
t_0	curve-fitting parameter related to the choice of reference time line
t_e	equivalent time
t_l	the time that post-surcharge secondary compression reappears after the removal of the surcharge
t_p	the time required for completion of the primary consolidation
t_{pr}	the time required for completion of the post-surcharge primary consolidation
$\mathrm{t'_{ps}}$	time to EOP compression under surcharge
$\mathrm{t'_s}$	the surcharging time
t_{total}	maximum calculation time
U	The degree of consolidation
$\mathrm{\overline{U}_h}$	he average degree of consolidation for axisymmetric flow
u	excess pore water pressure
$\mathrm{\bar{u}_i}$	the average pore water pressure
$\mathrm{u_{ni}}$	pore water pressure at any point in the natural soil zone

u_{si}	pore water pressure at any point in the smear zone
u_{vac}	vacuum pressure at any point
u_{wi}	the excess pore water pressure within vertical drain
z	vertical coordinate

Greek symbols

α	permeability ratio parameter
α_p	the instant deformation per unit thickness and unit load
α_s	secondary compression rate per unit thickness and unit load
β_1	permeability ratio parameter
β_2	permeability ratio parameter
γ_{sat}	saturated unit weight of soil
γ_w	unit weight of water
$(\Delta e)_p$	the change in the void ratio during the primary consolidation
Δr	radial distance increment
Δt	time step
Δz	vertical distance increment
$\Delta\sigma_{vs}$	he total surcharge pressure
$\dot{\varepsilon}^e$	elastic compression
$\dot{\varepsilon}^p$	time dependant compression
ε_z	soil vertical strain
ε_z^e	vertical strain at stress level σ'_z
ε_{z0}^e	vertical strain at $\sigma'_z = \sigma'_u$
ε_z^{ep}	reference time line strain
ε_{z0}^{ep}	vertical strain at $\sigma'_z = \sigma'_{z0}$
ε_{cr}^{limit}	creep strain limit
ε_z^{limit}	strain limit
$\dot{\varepsilon}_{ij}^{vp}$	the visco-plastic strain rate
ε_z^{vp}	creep compression strain
θ	the temperature
Λ	time-dependent multiplier
$\frac{\kappa}{v}$	material parameter describing the elastic stiffness of the soil
$\frac{\lambda}{v}$	material property describing the elastic-plastic stiffness of the soil
v	specific volume $(1 + e)$
$\overline{\sigma}'$	average effective stress
σ'_u	unit stress
σ'_{z0}	material property
σ'_{vf}	the final effective vertical stress after the removal of surcharge

σ'_{vs}	the maximum vertical effective stress reached immediately before removal of the surcharge
ς	the viscosity of the dashpot
τ	the non-linear viscous resistance of the dashpot
Υ	fluidity parameter
ϕ	viscous nucleus
$\frac{\psi_0}{v}$	initial creep coefficient